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Measurement of the wrong-sign decays $D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^+\pi^-\pi^+\pi^-$, and search for CP violation

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Abstract

Using 281 fb^{-1} of data from the Belle experiment recorded at or near the $\Upsilon(4S)$ resonance, we have measured the rates of the "wrong-sign" decays $D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^+\pi^-\pi^+\pi^-$ relative to those of the Cabibbo-favored decays $D^0 \to K^-\pi^+\pi^0$ and $D^0 \to K^-\pi^+\pi^+\pi^-$. These wrong-sign decays proceed via a doubly Cabibbo-suppressed amplitude or via D^0-$\overline{D}{}^0$ mixing; the latter has not yet been observed. We obtain $R_{\rm WS}(K\pi\pi^0) = [\,0.229 \pm 0.015\,({\rm stat.})^{+0.013}_{-0.009}\,({\rm sys.})\,]\%$ and $R_{\rm WS}(K3\pi) = [\,0.320 \pm 0.018\,({\rm stat.})^{+0.018}_{-0.013}\,({\rm sys.})\,]\%$. The CP asymmetries are measured to be -0.006 ± 0.053 and -0.018 ± 0.044 for the $K^+\pi^-\pi^0$ and $K^+\pi^-\pi^+\pi^-$ final states, respectively.

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Studies of mixing in the K^0-$\overline{K}^0$ and B^0-$\overline{B}^0$ meson systems [1] have had an important impact on the development of the Standard Model (SM). The latter allowed the top quark mass to be predicted prior to its direct observation. In contrast, the D^0-$\overline{D}^0$ mixing rate is strongly suppressed by Cabibbo-Kobayashi-Maskawa (CKM) factors and the GIM mechanism [2]; the SM predicted rate is far below current experimental upper limits. Observation of mixing significantly larger than this prediction could indicate new physics [3]. Previously, D^0-$\overline{D}^0$ mixing has been searched for in "wrong-sign" (WS) $D^0 \to K^+\pi^-$ decays [4, 5, 6], in WS $D^0 \to K^+\pi^-\pi^0$ and $D^0 \to K^+\pi^-\pi^+\pi^-$ decays [4, 7, 8], and in Dalitz-plot analyses of $D^0 \to K^0_s\pi^+\pi^-$ decays [9]. Here we investigate the WS multi-body modes $D^0 \to K^+\pi^-(n\pi)$ [10] with a data sample more than 30 times larger than that of previous studies. These modes can arise from a D^0 mixing into $\overline{D}^0$ and subsequently decaying via the "right-sign"(RS) Cabibbo-favored (CF) decay $\overline{D}^0 \to K^+\pi^-(n\pi)$. The final states can also arise from a doubly-Cabibbo-suppressed (DCS) amplitude; the ratio of DCS decays to CF decays can be used to measure the CKM phase ϕ_3 in $B^+ \to D^0K^+$ [11].

In this Letter we present measurements of the ratio of rates for WS to RS decays, $R_{\rm WS}^{(K^+\pi^-\pi^0)} \equiv \Gamma(D^0 \to K^+\pi^-\pi^0)/\Gamma(D^0 \to K^-\pi^+\pi^0)$ and $R_{\rm WS}^{(K^+\pi^-\pi^+\pi^-)} \equiv \Gamma(D^0 \to K^+\pi^-\pi^+\pi^-)/\Gamma(D^0 \to K^-\pi^+\pi^+\pi^-)$. Assuming negligible CP violation, this ratio is given by [12]

$$R_{\rm WS} \;=\; R_D + \sqrt{R_D}\,y' + \frac{1}{2}(x'^2 + y'^2)\,, \tag{1}$$

where R_D is the ratio of the magnitudes squared of the DCS to CF amplitudes; and x' and y' are "rotated" versions of the mixing parameters $x \equiv \Delta m/\overline{\Gamma}$ and $y \equiv \Delta\Gamma/2\overline{\Gamma}$: $x' = x\cos\delta + y\sin\delta$ and $y' = y\cos\delta - x\sin\delta$, where δ is an effective strong phase difference between the DCS and CF amplitudes [13]. The parameters x and y are mode-independent, depending only on the differences in mass (Δm) and decay width ($\Delta\Gamma$) between the two D^0-$\overline{D}^0$ mass eigenstates, and their mean decay width ($\overline{\Gamma}$).

The data sample consists of 281 fb^{-1} recorded by the Belle experiment at KEKB [14], an asymmetric e^+e^- collider operating at or near the $\Upsilon(4S)$ resonance. The Belle detector is a large-solid-angle magnetic spectrometer consisting of a silicon vertex detector (SVD), a 50-layer central drift chamber (CDC), an array of aerogel threshold Čerenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL), all located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux-return outside the coil is instrumented to detect K^0_L mesons and to identify muons (KLM). The detector is described in detail elsewhere [15, 16].

We consider the decay chain $D^{*+} \to D^0\pi^+_s \to K\pi(n\pi)\pi^+_s$, where the "slow" pion π^+_s has a characteristic soft momentum spectrum. The charge of π_s is used to identify whether a D^0 or $\overline{D}^0$ was initially produced. We require that all tracks have at least two SVD hits in both r-ϕ and z coordinates. We use information from the TOF, ACC, and CDC to select kaons (pions) with momentum dependent efficiencies of 80–95% (90–95%) and pion (kaon) misidentification probabilities of 5–20% (15–20%). To suppress background from semileptonic decays, we remove tracks identified as electrons (muons) based on ECL (KLM) information. We select π^0 candidates that satisfy 118 MeV/$c^2 < M_{\gamma\gamma} <$ 150 MeV/c^2 ($\pm3\sigma$ in resolution); we then apply a mass constrained fit for the photons. We require photon energies to be larger than 60 (120) MeV in the barrel (endcap) region.

$D^0 \to K^+\pi^-\pi^0$ candidates are reconstructed by combining two oppositely-charged tracks with a π^0 candidate having $p >$ 310 MeV/c in the center-of-mass (CM) frame. The $K^+\pi^-\pi^0$

invariant mass is required to be in the range 1.78–1.92 GeV/c^2 ($\pm 6\sigma$ in resolution). To reject background from $D^0 \to K^-\pi^+\pi^0$ in which the K is misidentified as π and the π as K, we calculate $m_{K\pi\pi^0}$ with the K and π assignments swapped and reject events having $m_{K\pi\pi^0(\text{swapped})}$ in the range 1.78–1.90 GeV/c^2.

$D^0 \to K^+\pi^-\pi^+\pi^-$ candidates are formed from combinations of four charged tracks; $m_{K3\pi}$ is required to be in the range 1.81–1.91 GeV/c^2 ($\pm 7\sigma$). To reject background due to misidentification of $D^0 \to K^-\pi^+\pi^-\pi^+$, we calculate $m_{K3\pi}$ with the K and π assignments swapped and reject events satisfying $|m_{K3\pi(\text{swapped})} - m_{D^0}| < 20$ MeV/c^2. The Cabibbo-suppressed decay $D^0 \to \overline{K}{}^0 K^+\pi^-$ followed by $\overline{K}{}^0 \to \pi^+\pi^-$ can also mimic the WS signal; to reject this background, we calculate $m_{\pi^+\pi^-}$ for both oppositely-charged pion combinations and reject events satisfying $|m_{\pi^+\pi^-} - m_{K^0}| < 16$ MeV/c^2.

The charged D^0 daughters are required to originate from a common vertex. The D^0 momentum vector is extrapolated back to the interaction point (IP) profile and a production vertex is determined. The D^{*+} candidate is then formed by combining the D^0 candidate with a π_s^+. We refit the π_s^+ track, requiring that it intersect the D^0 production point; this greatly suppresses combinatorial background and improves the resolution on the energy released in the D^* decay, $Q \equiv M_{\pi_s^+ K^+\pi^-(n\pi)} - M_{K^+\pi^-(n\pi)} - m_{\pi_s^+}$. For $D^{*+} \to D^0\pi_s^+$ decays, Q is only 5.85 MeV (slightly above threshold) and provides substantial background rejection. We subsequently require $Q < 12$ MeV, which is $> 99\%$ efficient.

To eliminate D mesons produced in $B\overline{B}$ events and further suppress combinatorial background, the reconstructed D^{*+} momentum in the CM frame is required to be greater than 2.5 GeV/c. Finally, we require that the χ^2 per degree of freedom (d.o.f) resulting from the D^0 vertex fit, the IP vertex fit, and the π_s track refit be satisfactory. The fraction of events containing multiple signal candidates is less than 3% for both modes (and is the same for RS and WS decays); multiple signal candidates are retained for subsequent analysis.

We determine the RS and WS signal yields by performing binned maximum likelihood fits in M-Q space with $M = M_{K\pi(n\pi)}$. The signal and background distributions are determined using a large Monte Carlo (MC) sample [17]. The backgrounds can be divided into three categories: (*a*) "random π_s" background, in which a random π^+ is combined with a true $\overline{D}{}^0 \to K^+\pi^-(n\pi)$ decay; (*b*) charm decay background other than (a); and (*c*) background from continuum $e^+e^- \to u\bar{u}, d\bar{d}$, or $s\bar{s}$ production.

The RS signal shape as predicted by MC simulation is parameterized in M with a sum of a double Gaussian and a double bifurcated Gaussian with common mean, and in Q with a bifurcated Student's t function. Background distributions are parameterized with similar empirical expressions determined from MC simulation. In the RS sample fit, the mean and width of the signal distribution are left free to vary, while other parameters are fixed to MC values. The relative normalizations of individual background categories are fixed to MC values for the $D^0 \to K^+\pi^-\pi^0$ fit, and left free for the $D^0 \to K^+\pi^-\pi^+\pi^-$ fit. In the WS sample fit, the mean and width of the signal are fixed to the values obtained from the RS fit; the normalizations of the backgrounds are left free to vary.

The RS sample fit obtains a signal yield of $(8.683 \pm 0.002) \times 10^5$ for $D^0 \to K^-\pi^+\pi^0$ and $(5.259 \pm 0.002) \times 10^5$ for $D^0 \to K^-\pi^+\pi^+\pi^-$. The WS fit finds 1978 ± 104 for $D^0 \to K^+\pi^-\pi^0$ and 1721 ± 75 for $D^0 \to K^+\pi^-\pi^+\pi^-$. The fit results are projected onto the M and Q distributions in Fig. 1 for $D^0 \to K^+\pi^-\pi^0$ and in Fig. 2 for $D^0 \to K^+\pi^-\pi^+\pi^-$. The hatched histograms show the fit results and the points with error bars show the data.

In $D^0 \to K\pi(n\pi)$ decays, intermediate resonances dominate the decay rate and cause a nonuniform event distribution in phase space. Since RS and WS decays may have different

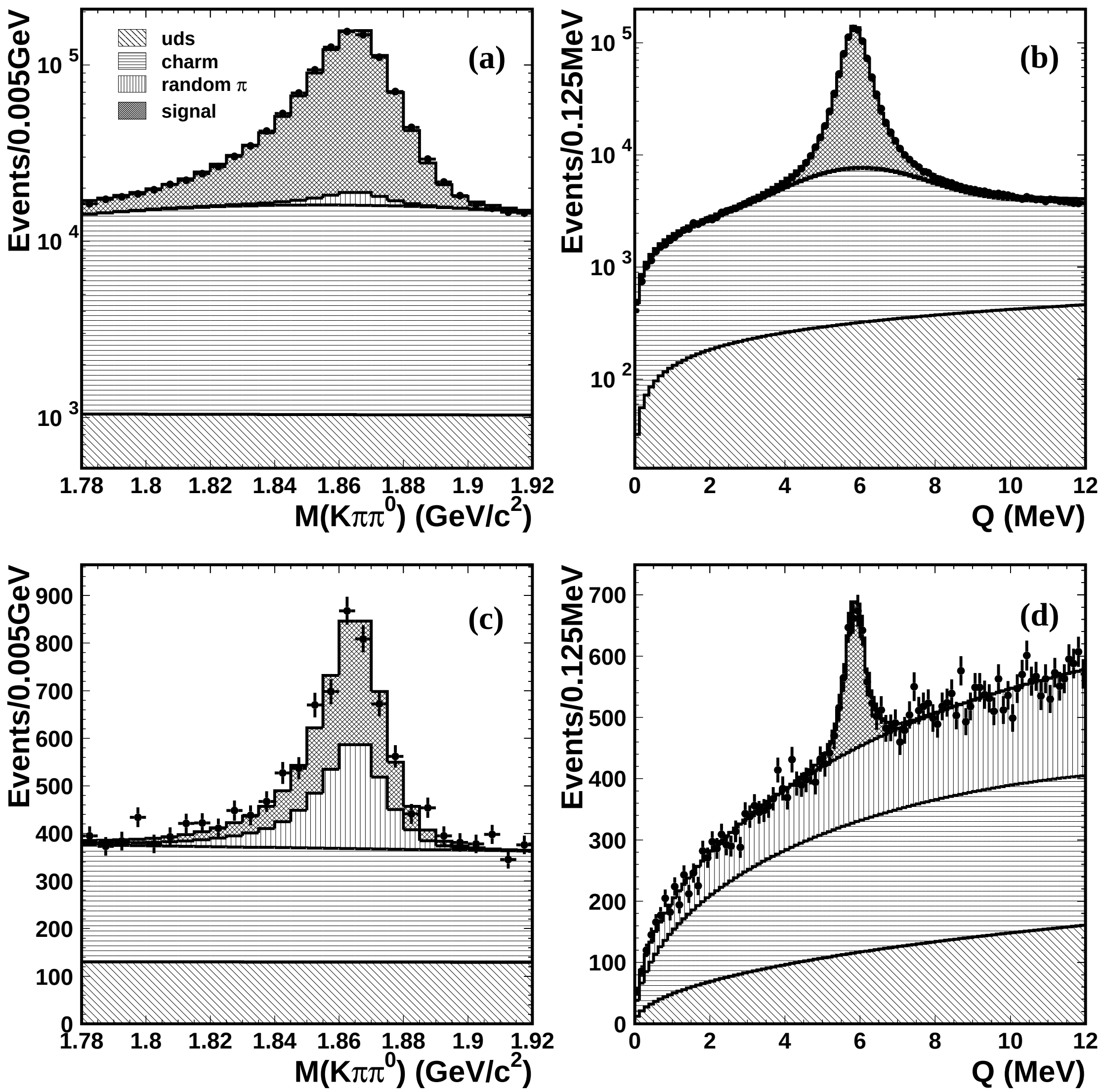

FIG. 1: Results of the M-Q fit for $D^0 \to K^+\pi^-\pi^0$, in projections onto (a) RS $M_{K\pi\pi^0}$ with $0\ \mathrm{MeV} < Q < 12.0\,\mathrm{MeV}$; (b) RS Q with $1.780\,\mathrm{GeV}/c^2 < M_{K\pi\pi^0} < 1.920\,\mathrm{GeV}/c^2$; (c) WS $M_{K\pi\pi^0}$ with $5.31\,\mathrm{MeV} < Q < 6.42\,\mathrm{MeV}$; and (d) WS Q with $1.844\ \mathrm{GeV}/c^2 < M_{K\pi\pi^0} < 1.887\ \mathrm{GeV}/c^2$.

resonant substructure, their acceptances may differ. We correct the event yields for acceptance and reconstruction efficiency as follows. For $D^0 \to K^\pm\pi^\mp\pi^0$, we determine efficiencies using MC simulation in bins of $(M^2_{K\pi},\, M^2_{\pi\pi^0})$; for $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$, we use bins in a five-dimensional space comprised of the invariant mass squared for various K,π combinations. We then calculate efficiency-corrected signal yields in each bin for the RS and WS samples. The background is taken to be the overall background yield multiplied by the fraction falling in that bin; the distribution of background among the bins is taken from the sideband $|Q - 5.85\ \mathrm{MeV}| > 2.0\ \mathrm{MeV}$. The resulting signal yields are summed over all bins, and the ratio of the total signal yields gives R_{WS}. The results are $R_{\mathrm{WS}}^{K^+\pi^-\pi^0} = (2.29 \pm 0.15) \times 10^{-3}$ and $R_{\mathrm{WS}}^{K^+\pi^-\pi^+\pi^-} = (3.20 \pm 0.18) \times 10^{-3}$, where the errors are statistical only.

The average efficiency for a mode is obtained by dividing the signal yield from the M-Q

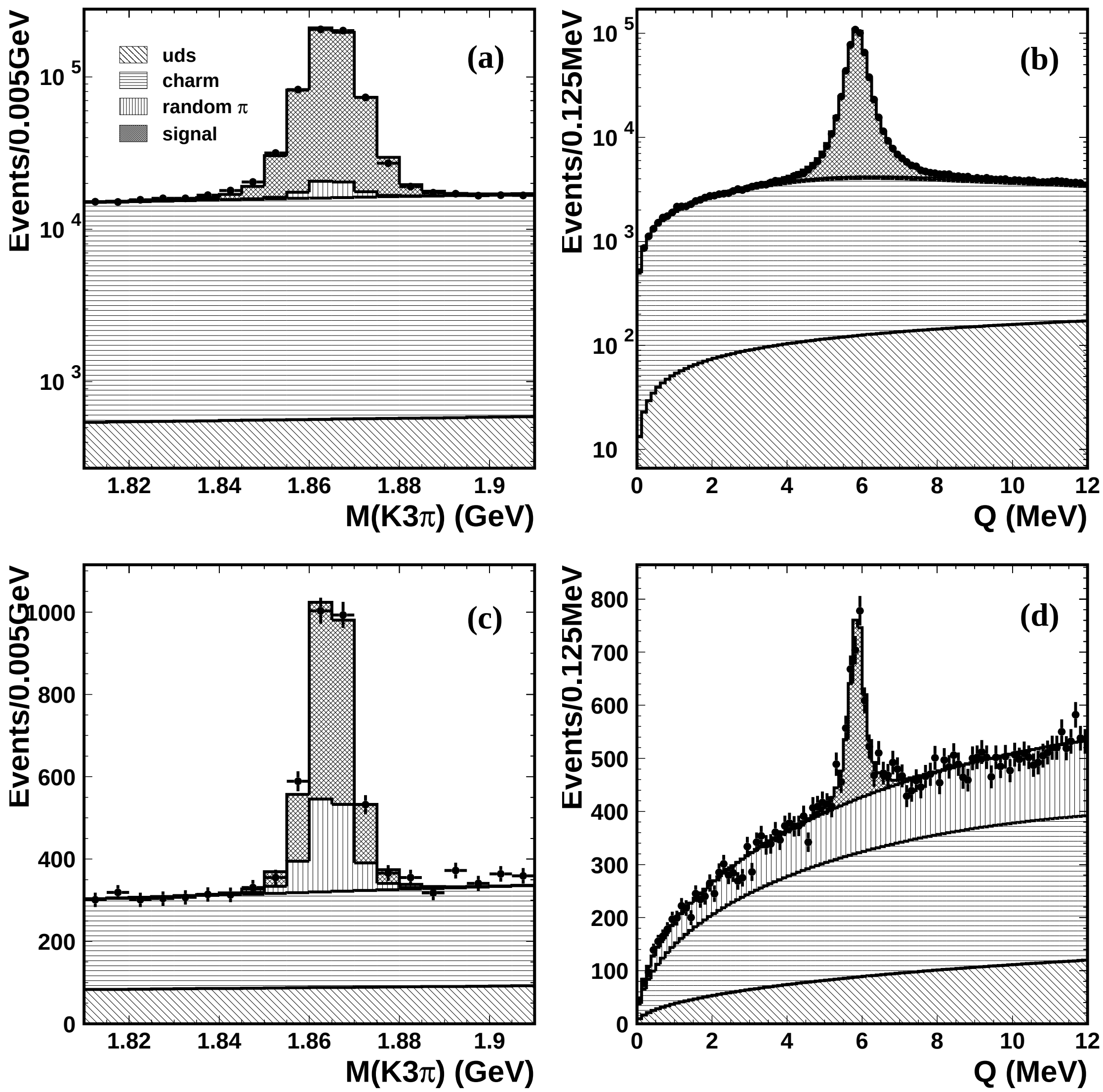

FIG. 2: Results of the M-Q fit for $D^0 \to K^+\pi^-\pi^+\pi^-$, in projections onto (a) RS $M_{K3\pi}$ with $0\text{ MeV} < Q < 12.0\,\text{MeV}$; (b) RS Q with $1.810\,\text{GeV}/c^2 < M_{K3\pi} < 1.910\,\text{GeV}/c^2$; (c) WS $M_{K3\pi}$ with $5.47\,\text{MeV} < Q < 6.28\,\text{MeV}$; and (d) WS Q with $1.852\,\text{GeV}/c^2 < M_{K3\pi} < 1.878\,\text{GeV}/c^2$.

fit by the total efficiency-corrected signal yield; the ratio of average efficiencies $\langle\varepsilon_{\rm RS}\rangle/\langle\varepsilon_{\rm WS}\rangle$ is 1.01 ± 0.05 for $D^0 \to K^\pm\pi^\mp\pi^0$ and 0.98 ± 0.04 for $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$.

Contributions to the systematic uncertainty on R_{WS} are listed in Table I: the size of each term is assessed by varying the analysis as described below and repeating the fits. Many effects cancel in the ratio due to the similar kinematics of the RS and WS modes; one distinction is the significant background contribution to the WS sample. We vary the selection criteria over reasonable ranges (the WS yield changes by $\sim 10\%$); the largest positive and negative variations in $R_{\rm WS}$ are assigned as systematic errors. We check the parameterization of the signal shape by varying the means and widths in M and Q by $\pm 1\sigma$. We check background fractions and parameterizations by varying individual fractions and distribution parameters by $\pm 1\sigma$; we also try alternative functional forms. We investigate

TABLE I: Systematic uncertainties for $R_{\rm WS}$, in percentage.

Source	$D^0 \to K^+\pi^-\pi^0$		$D^0 \to K^+\pi^-\pi^+\pi^-$	
Selection criteria	$+5.22$	-2.38	$+5.25$	-3.78
Signal shape param.	$+0.09$	-0.10	$+0.10$	-0.10
Background fraction	$+0.00$	-0.07	$+0.01$	-0.01
Background param.	$+0.42$	-2.89	$+0.34$	-0.59
Possible fit bias	$+2.23$	-0.94	$+0.91$	-0.88
Total	$+5.7$	-3.9	$+5.4$	-4.0

possible fit bias by fitting a large MC RS sample; the small difference between the fitted yield and the true number of RS events is taken as an additional systematic error. The total systematic error is obtained by combining the individual terms in quadrature.

Assuming a value for x', Eq. (1) can be used to constrain R_D as a function of y'. This constraint is shown in Fig. 3 for $x'=0$ and $|x'|=0.028$; the latter value is the 95% CL upper limit on $|x'|$ obtained from our previous analysis of $D^0 \to K^+\pi^-$ decays [6]. Values of (x', y') for different decay modes would be equivalent if the strong phase differences (δ) for the modes were equal. In the absence of mixing (i.e., $x = y = 0$), our measurements give $R_D(K\pi\pi^0) = (0.85\,^{+0.08}_{-0.07})\tan^4\theta_C$ and $R_D(K3\pi) = (1.18\,^{+0.10}_{-0.09})\tan^4\theta_C$ (θ_C is the Cabibbo angle), consistent with theoretical expectations [18].

By separately fitting the D^0 and $\overline{D}{}^0$ samples, we measure the CP asymmetry

$$A_{CP} = \frac{R_{\rm WS}^{D^0\to K^+\pi^-(n\pi)} - R_{\rm WS}^{\overline{D}{}^0\to K^-\pi^+(n\pi)}}{R_{\rm WS}^{D^0\to K^+\pi^-(n\pi)} + R_{\rm WS}^{\overline{D}{}^0\to K^-\pi^+(n\pi)}}\,.$$

We obtain $A_{CP}(K\pi\pi^0) = -0.006 \pm 0.053$ and $A_{CP}(K3\pi) = -0.018 \pm 0.044$, which are both consistent with zero. The systematic uncertainties are <0.01 (much smaller than the statistical errors) and are neglected. The first value represents a large improvement over the previously-published result [7]; the second value has not been previously measured.

In summary, using 281 fb^{-1} of data we measure the ratio of WS to RS decay rates for $D^0 \to K^\pm\pi^\mp\pi^0$ and $D^0 \to K^\pm\pi^\mp\pi^+\pi^-$ to be

$$R_{\rm WS}^{K^+\pi^-\pi^0} = \left[2.29 \pm 0.15\,({\rm stat})\,^{+0.13}_{-0.09}\,({\rm syst})\right] \times 10^{-3}$$

$$R_{\rm WS}^{K^+\pi^-\pi^+\pi^-} = \left[3.20 \pm 0.18\,({\rm stat})\,^{+0.18}_{-0.13}\,({\rm syst})\right] \times 10^{-3}\,.$$

These results are much more precise than previously-published results [4, 7, 8]. The CP asymmetries measured are consistent with zero.

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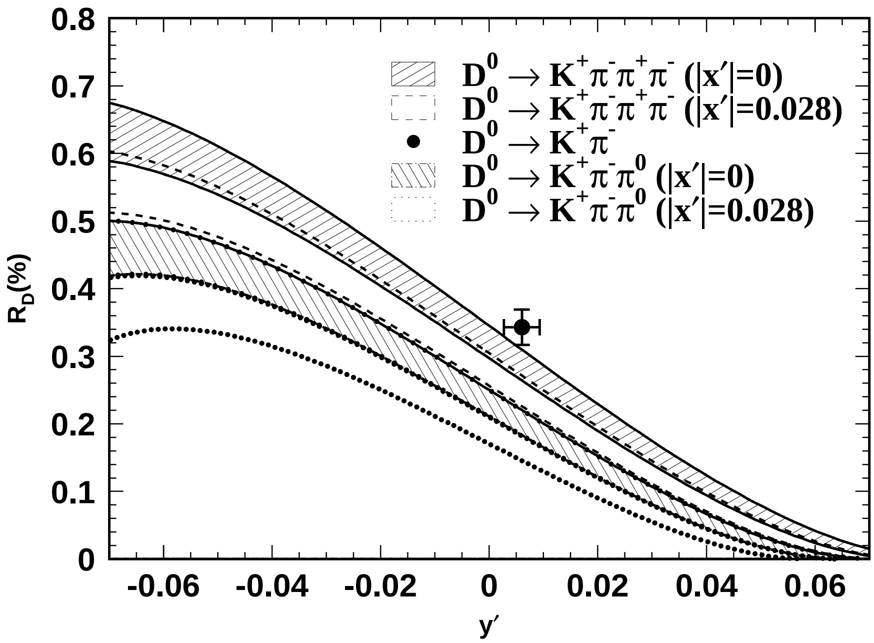

FIG. 3: 68.3% CL bands for R_D as a function of y' for $x' = 0$ and $|x'| = 0.028$. The latter value is the upper limit obtained from our analysis of $D^0 \to K^+\pi^-$ decays assuming no CP violation [6]. The point with 1σ error bars is the result from the $D^0 \to K^+\pi^-$ analysis for $x' = 0$ (and no CP violation). Note that δ and thus x', y' may differ for the three modes.

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[1] R.H. Good *et al.*, Phys. Rev. **124**, 1223 (1961); H. Albrecht *et al.* (ARGUS Collab.), Phys. Lett. B **192**, 245 (1987).

[2] S.L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D **2**, 1285 (1970).

[3] For a review see S. Bianco, F. L. Fabbri, D. Benson, and I. Bigi, Riv. Nuovo Cim. **26N7-8**, 1 (2003).

[4] E. Aitala *et al.* (E791 Collab.), Phys. Rev. D **57**, 13 (1998);

[5] R. Godang *et al.* (CLEO Collab.), Phys. Rev. Lett. **84**, 5038 (2000); B. Aubert *et al.*, (BaBar Collab.), Phys. Rev. Lett. **91**, 171801 (2003).

[6] J. Li *et al.* (Belle Collab.), Phys. Rev. Lett. **94**, 071801 (2005).

[7] G. Brandenburg *et al.* (CLEO Collab.), Phys. Rev. Lett. **87**, 071802 (2001).

[8] S. A. Dytman *et al.* (CLEO Collab.), Phys. Rev. D **64**, 111101 (2001).

[9] H. Muramatsu *et al.* (CLEO Collab.), Phys. Rev. Lett. **89**, 251802 (2002); D. M. Asner *et al.* (CLEO Collab.), Phys. Rev. D **72**, 012001 (2005).

[10] Charge-conjugate states are implied throughout this paper. We write $D^0 \to K^+\pi^-(n\pi)$ to denote both $D^0 \to K^+\pi^-\pi^0$ $(n=1)$ and $D^0 \to K^+\pi^-\pi^+\pi^-$ $(n=2)$.

[11] D. Atwood, I. Dunietz, and A. Soni, Phys. Rev. D **63**, 036005 (2001).
[12] G. Blaylock, A. Seiden, and Y. Nir, Phys. Lett. B **355**, 555 (1995).
[13] The parameters R_D and δ represent averages over submodes contributing to the $K\pi\pi^0$ and $K\pi\pi\pi$ final states.
[14] S. Kurokawa and E. Kikutani, Nucl. Instr. and. Meth. A499, 1 (2003), and other papers included in this volume.
[15] A. Abashian *et al.* (Belle Collab.), Nucl. Instr. and Meth. A **479**, 117 (2002).
[16] Y. Ushiroda (Belle SVD2 Group), Nucl. Instr. and Meth. A **511**, 6 (2003).
[17] Events are generated with the CLEO QQ generator (see http://www.lns.cornell.edu/public/CLEO/soft/QQ); the detector response is simulated with GEANT 3.21, R. Brun *et al.*, CERN Report DD/EE/84-1, 1984.
[18] S. Bianco *et al.*, op. cit. pp. 146-147.